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A MINE SWEEPER COMPUTER SIMULATION

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by

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ABSTRACT:

A probabilistic computer simulation, constructed under very simplifying assumptions, of mine sweeper operations is presented. The model is described along with its associated input and output formats. A listing of the CDC FORTRAN-60 program and a sample output from several computer runs are included. The model was constructed as a pedagogical tool in an attempt to familiarize beginning students of Operations Research with the Monte Carlo method as applied in computer war gaming.

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SECTIONS

1. The Problem

From an analyst's point of view, a typical mine field operation concerned only with the laying of mines and the effectiveness of a desired mine field can be partitioned into the following activities:

1. laying the mines;
2. sweeping the mine field;
3. transiting the mine field with normal traffic.

With these activities in mind, the analyst may then desire answers to the following questions:

1. How effective is a planned mine field?
2. How effective is a given capability to eliminate the mine field?
3. What density of mines is required to thwart the transit of normal traffic?
4. What level of mine sweeping is required to maintain a certain level of transit?

Among the methods available to an analyst in order to try and answer these questions is the important one of carrying out the operation, both offensively and defensively, and observing the results. By actually planning and laying a mine field, attempting to sweep the field, and also attempting to transit the field, the analyst can arrive at judgments as to how well the mines, mine layers, and mine sweepers achieve their objectives and at what level of activity these objectives appear to be maximized. This may well be the best way to answer the above questions. However, the ordinary restrictions of time, cost and men may not permit the actual operation to be performed.

An immediate question of concern then is, "How can the analyst possibly answer these questions, and many more, within a reasonable time and cost environment?" One answer, and in many instances not the only answer, is for the analyst to simulate the operation and generate his data via the process of simulation. How close the simulation results will be to the actual operation results might be very debatable. The proximity of simulated and operational data will of course depend on how closely the simulated exercise approximates the actual operation.

There are several methods of simulation available to an analyst, including the digital computer which can quite easily be used as the mechanism of the simulation. If the operation can be described logically so that it is amenable to being programmed, a computer program can be written to play through the simulation and generate the required data. The major advantage of a digital computer simulation is the speed with which the simulation can be played and replayed. The following sections of this report describe such a program, under simplifying assumptions, which can provide the analyst with the simulation tool needed to approximate or generate expected value results for the questions posed earlier.

II. General Model Description

MSF is a computer simulation of a typical mine field operation. The computer inputs, supplied by the model user, are in general:

1. Offensive Parameters

   a) description of playing area
   b) number of mine laying vehicles
   c) number of mines laid by each vehicle
   d) desired entry points into the area for each vehicle and the desired position of each mine
   e) maximum errors for vehicle entry points and mine positions
   f) mine effectiveness

2. Defensive Parameters

   a) number of mine sweepers
   b) mine sweeper entry points into the area
   c) mine sweeper effectiveness
   d) number of ships to transit the area
   e) range of entry points into the area for the transiting ships

3. Game Parameters

   a) number of samples
   b) sample size

A complete description of these inputs is included in Section IV.

With these computer inputs the computer program MSF proceeds as indicated in Figure 1. At the end of the program indicated by the block labeled STOP in Figure 1, the program user has available the computer output. The output information consists of, in general, the expected number of ships safe out of the total number of ships attempting to transit the area as a function of the number of mine sweeper passes through the mine field. By varying the values assigned to the input parameters and replaying the model the analyst can then arrive at different sets of output data which can be used in a comparative fashion in order to determine the significant levels of activities included in the model. The significant levels of activities of course depend upon what

GENERAL FLOWCHARTS

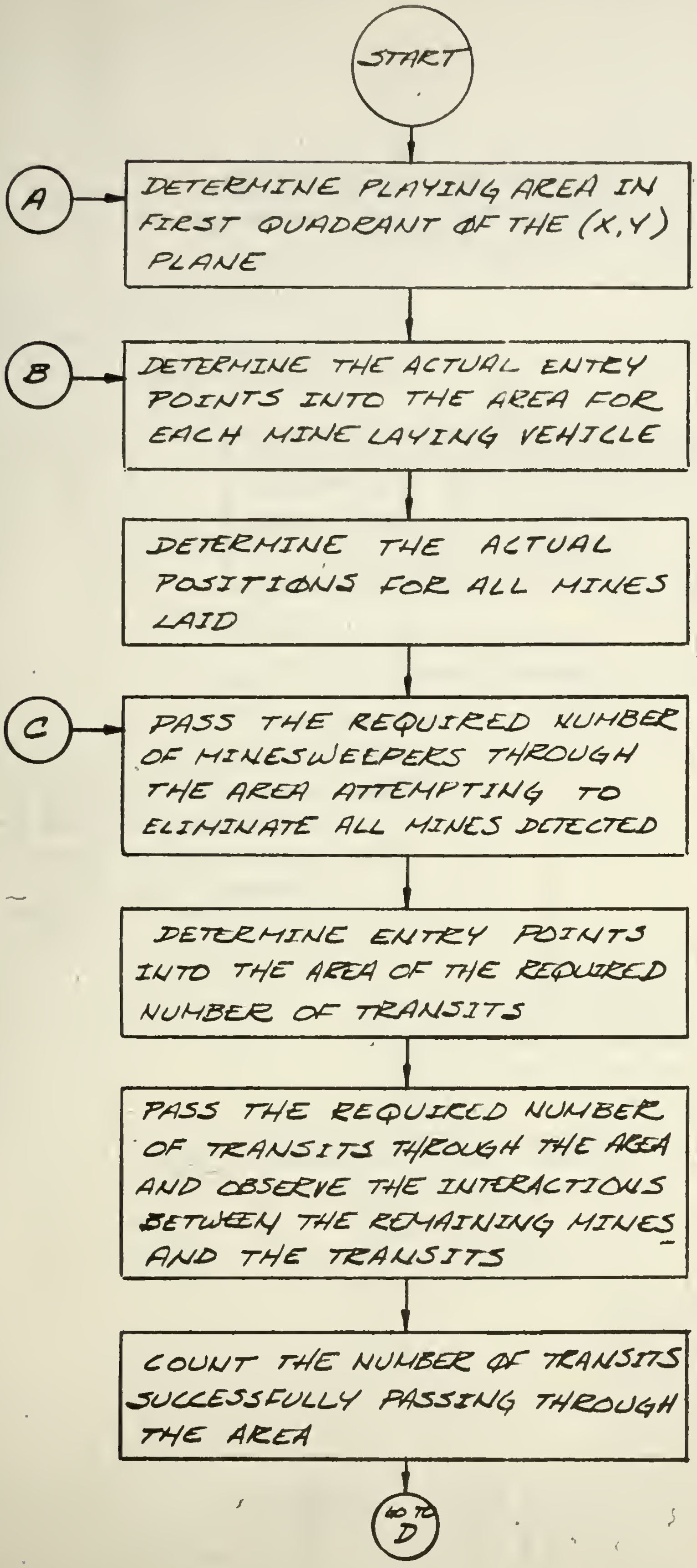


FIGURE 1.

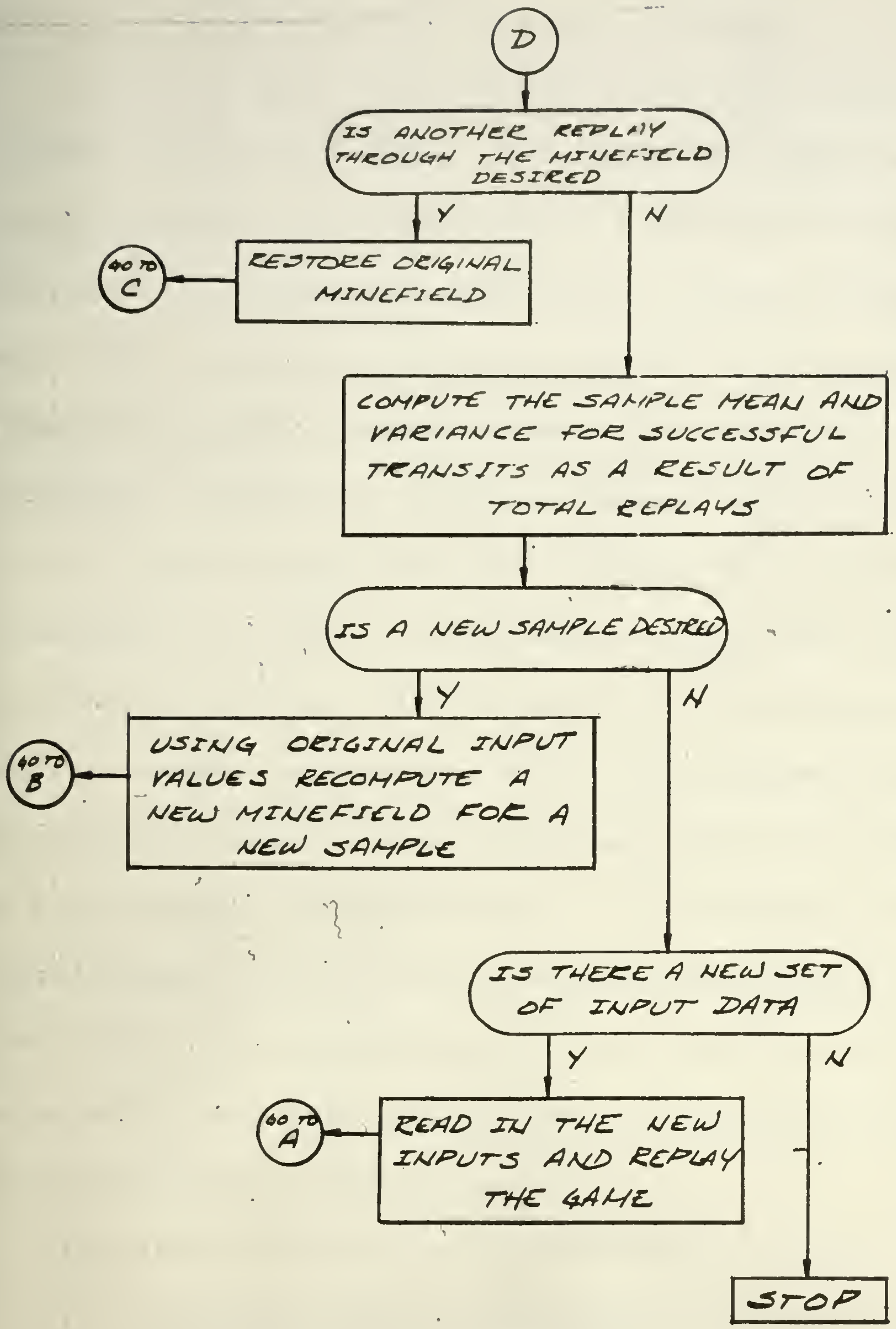


FIGURE 1 (CONT'D)

activity or activities the analyst is trying to optimize.

In essence, from Figure 1, it appears that MSF realistically simulates the actual operation. The activities in a typical mine field operation appear to be present in MSF. What has not been mentioned however are the assumptions upon which the computer program is built. After examining these assumptions MSF will seem quite removed from reality and it is therefore very important for the analyst using MSF to interpret the computer output and any inferences drawn from this output in light of these assumptions. This is not to say the assumptions may be bad. The assumptions may be quite adequate for examining the activities of the operation as they are included in the model. It must be stressed however that the assumptions were made in an effort to simplify the logical structure of the mining operat ion in order to build a computer program which would yield a first approximation as answers to some of the questions posed earlier. If one or more of the assumptions are too unrealistic to suit the needs of an analyst he may either not use the model or refine the model to eliminate whatever objections he may have.

The assumptions inherent in the MSF computer program are:

1. All mine laying vehicles attempt to maintain a course through the area parallel to the sides of the area.

2. All errors computed in order to determine the entry points of delivery vehicles and the positions of mines are assumed to be distributed according to a uniform density function, defined between the ranges of maximum and minimum error.

3. The distributions for the error in delivery vehicle entry points are identical.

4. The distributions for the error in mine positions are identical. Assumptions 3 and 4 indicate that in the model there is no difference in the ability of the delivery vehicles to enter the area as desired or in laying the mines in the desired positions.

5. A mine sweeper makes only one pass through the area maintaining a course parallel to the sides of the area.

6. The effectiveness of all mine sweepers is identical.

7. The entry points of the transits are assumed to be distributed according to a triangular distribution, defined between the ranges of maximum and minimum entry points. The maximum and minimum entry points are equidistant from the sides of the area and the triangular distribution is centered upon the middle of the area.

8. All transits maintain a course through the area parallel to the side of the area.

9. The effectiveness of all mines is identical.

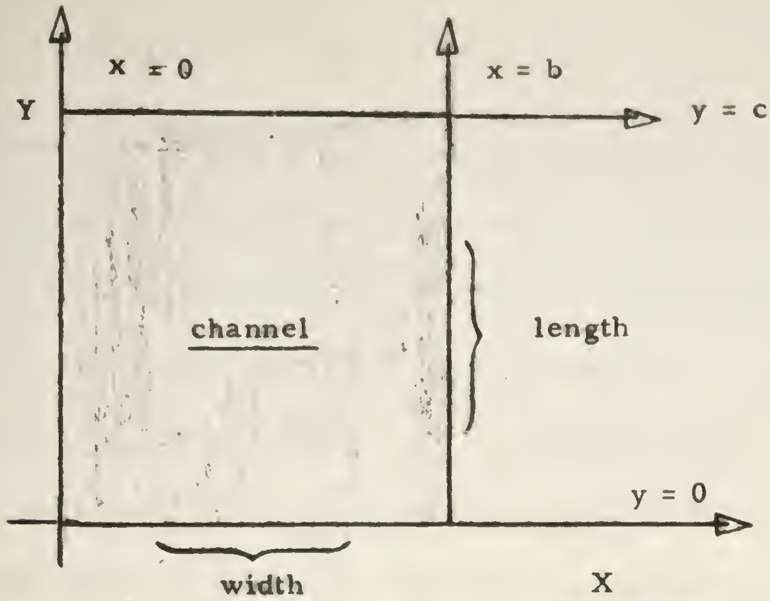
It can now be observed that MSF might be very unrealistic. A given mine field operation might well include the laying of different types of mines with different values of effectiveness, more than one type of delivery vehicle might be used with different operating characteristics, etc. However, as in the construction of any model, using the simplifying assumptions has led to a model that provides an "approximation" to desired results and one that hopefully is flexible enough to allow changes in its structure in order that the model results will closer approximate the real operation. For an analyst to change the structure of the model in order to make the model meet his needs, he now must have not only an understanding of the operation being modeled but an understanding of the existing model as well.

To the beginning student in operations research it should be pointed out here that if model results appear to contradict intuitive notions of what results ought to be, the intuitive results might be just as questionable as the model results. Also if model results and intuitive results agree this is not to say that both are correct.

III. Detailed Model Description

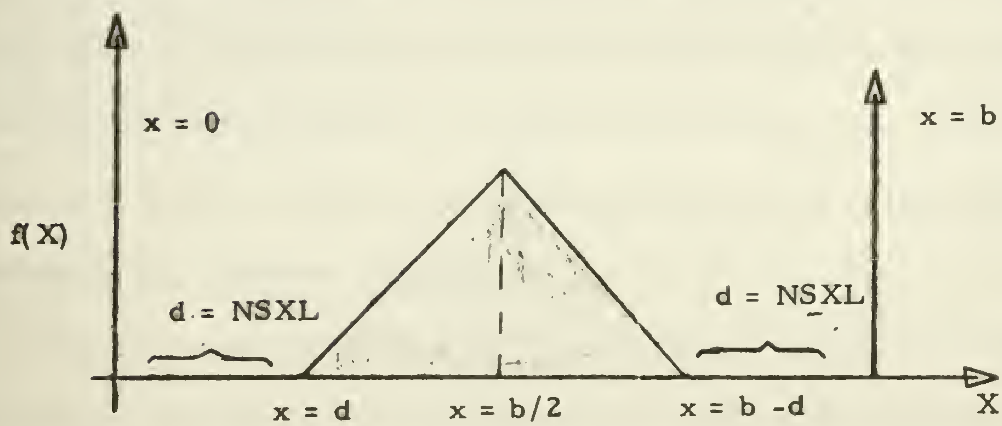
As indicated earlier in Figure 1, the following events occur in the computer program for MSF: delivery vehicles attempt to drop mines in a channel, mine sweepers attempt to sweep the channel, and ships are sent through the channel in an effort to successfully transit through the mine field. The outcome of events such as the actual location of mines, sweeping of mines, and the destruction of ships passing through the channel are determined using Monte Carlo techniques, i. e., with each event is associated a probability of success, and the success or failure of any event is determined by comparing a computer generated random number with the associated probability. The random numbers are generated according to the characteristics of the density functions describing the probability of occurrence of each event. The random numbers used in the MSF program should rightfully be called pseudo random numbers since they are generated by an arithmetic process and can always be determined or predicted according to this process.

The playing area of the model is a specified rectangle in the first quadrant of the (X, Y) plane which represents a channel. See Figure 2.



The playing area as constructed in the first quadrant.

FIGURE 2



Description of density function describing transit ship entry points.

FIGURE 3

The desired entry points into the channel for all delivery vehicles and mine sweepers are defined as integer values in the interval $0 \leq x \leq b$ on the line $y = 0$ as illustrated in Figure 2. The desired positions of all mines layed from a particular delivery vehicle are defined as integer values in the interval $0 \leq y \leq c$ along the line $x = k$, where $x = k$ is the desired path of the delivery vehicle and $0 \leq k \leq b$. The entry points into the channel for the transiting ships, once an attempt has been made to sweep the channel, are determined by generating random numbers corresponding to integer values in the interval $d \leq x \leq b-d$ on the line $y = 0$ according to the density function described as in Figure 3 where the value of d is determined by the model user.

To illustrate the computer techniques used in the model, a partial listing of the FORTRAN language program will parallel a description of the method being used in the computation of each event. In this manner, it is hoped some understanding will be gained of the restrictions inherent in any computer simulation.

It should be mentioned that all of the logical procedures involved in the operation have been translated into the arithmetic statements of addition, subtraction, compare, etc. in order to write the computer program. For the MSF program a FORTRAN subroutine called RAND was written to generate numbers uniformly distributed on the interval

(0, 1). When a call to RAND is made in the MSF program a number in the interval (0, 1) is generated and stored in the program variable name NX. All random numbers used in the MSF program are then generated by transformations on the value of NX. To generate an integer uniformly distributed on the integer interval (0, 200) the program variables NRNC and NXIN are used: The number 200 is placed in location NRNC before the call to RAND is made, CALL RAND is executed and in location NX is placed a number generated on the interval (0, 1) and in NXIN is placed an integer on the interval (0, 200) based upon the value of NX.

The FORTRAN program, MSF, consists of several subroutines for control, input and output purposes, but the actual mine field simulation lies in subroutine MINSIM which is described in the following section.

FORTRAN Program

```
      DO 10 I=1, NRMINE
      MINENR(I) = 0
      MINEX(I) = NULL
10    MINEY(I) = NULL
```

For each play of the game a minetable consisting of the actual X and Y coordinates, MINEX(I) and MINEY(I), and the mine number, MINENR(I), of all mines is created. At the beginning of play this table is nulled as indicated by the partial program. The variable NRMINE contains an input value specifying the number of mines used for this play of the game. The table is nulled by storing the constant NULL = 377777777777777_8 into the MINEX(I) and MINEY(I) locations and zero into location MINENR(I).

```
      J = 1
      DO 20 I=1, NRAIR
      NRNC = NYERR1
      CALL RAND
      MINEY(J) = NXIN + MINED(J) - NYERR1/2
      NRNC = NXERR1
      CALL RAND
      MINEX(J) = NXIN + NACEPT(I) - NXERR1/2
      MINENR(J) = J
20    J = J + NRMPAC(I)
```

The actual location of the first mine dropped by each delivery vehicle is now determined and placed in the minetable. For the partial program illustrated: NRAIR is the number of delivery vehicles in this play of the game, NXERR1 and NYERR1 are the maximum values of the errors in the X and Y directions allowed in computing actual vehicle entry points, NRMPAC(I) is the number of mines carried by vehicle I, NACEPT(I) is the desired entry point along the width of the channel for vehicle I, MINED(J) is the desired Y coordinate for mine number J, and MINEX(J) and MINEY(J) are the actual X and Y coordinates as computed for mine number J. In the computer program mines are identified by numbering them sequentially, i.e., if vehicle number one contains eight mines, the first mine dropped from vehicle number two is identified as mine number nine, etc. In the above computation MINEX(J) and MINEY(J) are determined by selecting integers X and Y respectively in the ranges

$$\text{NACEPT(I)} - \frac{\text{NXERR1}}{2} \le x \le \text{NACEPT(I)} + \frac{\text{NXERR1}}{2}$$

$$\text{MINED(J)} - \frac{\text{NYERR1}}{2} \le y \le \text{MINED(J)} + \frac{\text{NYERR1}}{2}$$

where it is assumed that all integers in the ranges have an equal

probability of being selected. This is accomplished by using the random number generator to generate NXIN where for MINEX(J)

$$0 \le NXIN \le NXERR1$$

and then

$$MINEX(J) = NXIN + NACEPT(I) - \frac{NXERR1}{2}$$

and for MINEY(J)

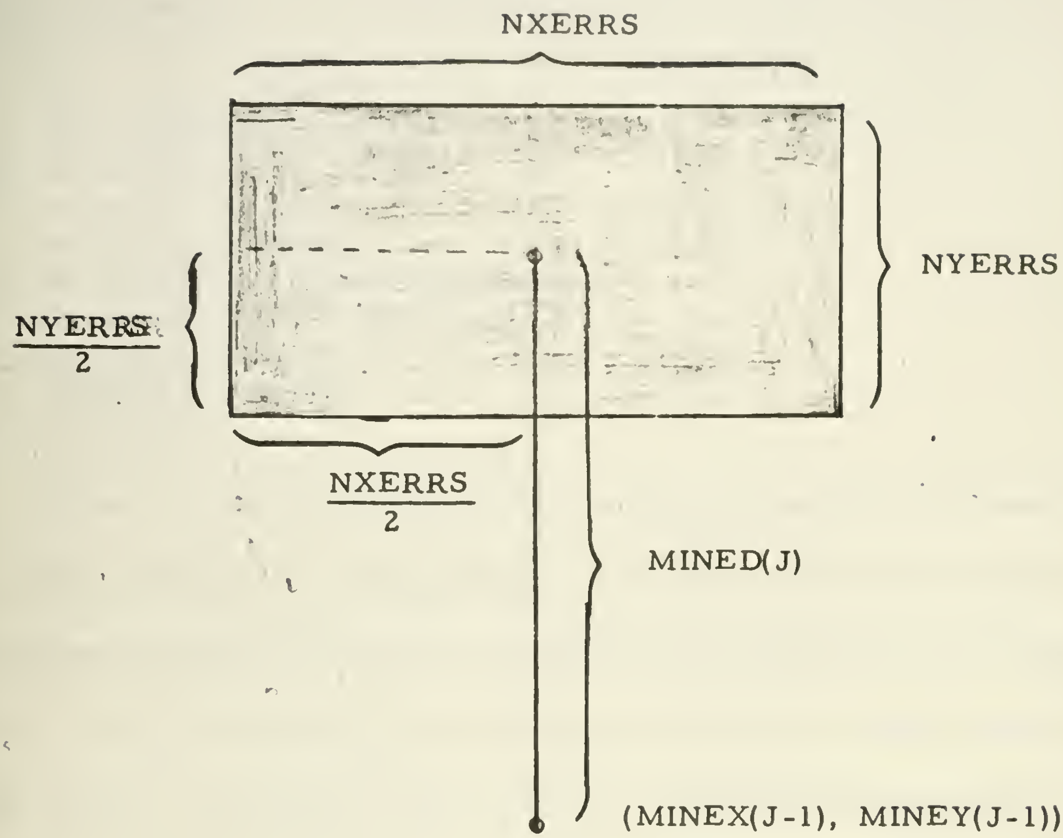
$$0 \le NXIN \le NYERR1$$

and then

$$MINEY(J) = NXIN + MINED(J) - \frac{NYERR1}{2}$$

```
      DO  30 J=1, NRMINE
      IF (MINEY(J)-NULL) 30, 22, 30
22    NRNC=NYERRS
      CALL RAND
      MINEY(J)=NXIN+MINED(J)+MINEY(J-1)-NYERRS/2
      NRNC=NXERRS
      CALL RAND
      MINEX(J)=NXIN+MINEX(J-1)-NXERRS/2
      MINENR(J)=J
30    CONTINUE
```

A similar process is then repeated to determine the actual location of all other mines and store these values in the mine table. In this computation NXERRS and NYERRS are the maximum values of the errors in the X and Y directions for computing actual mine locations. MINEX(J) and MINEY(J) are then determined as in the previous paragraph using NXERRS and NYERRS in place of NXERR1 and NYERR1. Figure 4 illustrates the possible locations for mine number (J) given the location of mine number (J-1) for two mines dropped consecutively



For two mines numbered (J) and (J-1) dropped consecutively from the same vehicle the shaded area represents the area in which mine number (J) will be located given the location of mine number (J-1).

FIGURE 4

from the same delivery vehicle as determined by the above computation. The purpose of the IF statement in this partial program is to skip over the computation for the X and Y coordinates for the first mine dropped from each vehicle.

```
      DO 40 I=1, NRMINE
      IF (MINEX(I)) 39, 38, 38
38    IF (MINEY(I)) 39, 37, 37
39    MINEX(I)=NULL-7
      MINEY(I)=MINEX(I)
37    IF (MINEY(I)-NCHANL) 31, 33, 33
31    IF (MINEX(I)-NCHANW) 40, 33, 33
33    MINEY(I)=NULL-1
      MINEX(I)=MINEY(I)
40    CONTINUE
```

At the completion of the previous partial program the minetable has been created, i.e., the locations of all mines have been determined and these locations are stored in MINEX(J) and MINEY(J). The minetable is now examined to determine if any mines are located outside the channel. Any mine location with (X, Y) coordinates outside the channel is eliminated from the channel by setting the coordinate of mines located in quadrants II, III, or IV to NULL-7, and for those mines outside of the channel but still in quadrant I, the coordinates are set to NULL-1. For this partial program NCHANL and NCHANW are the length and width of the channel respectively.

```
      J=NRMINE
50    K=J
      J1=J-1
      DO  60 I=1, J1
      IF (MINEY(I)-MINEY(K)) 55, 60, 60
55    K=I
60    CONTINUE
      NT1=MINENR(J)
      MINENR(J)=MINENR(K)
      MINENR(K)=NT1
      NT1=MINEX(J)
      MINEX(J)=MINEX(K)
      MINEX(K)=NT1
      NT1=MINEY(J)
      MINEY(J)=MINEY(K)
      MINEY(K)=NT1
      J=J-1
      IF (J-1) 70, 70, 50
```

The minetable is now reordered as a function of the Y coordinate of each mine location. With all mine locations determined and the minetable reordered the mine laying phase of the operation is complete.

```
70    IF(NRMSWP) 140, 140, 80
80    DO  130 I=1, NRMSWP
      NLOLIM=MSWEP(I)-MSWWID/2 -1
      NUPLIM=NLOLIM+MSWWID  + 2
      DO  120 J=1, NRMINE
      IF (NLOLIM-MINEX(J)) 90, 120, 120
90    IF (MINEX(J)-NUPLIM) 100, 120, 120
100   CALL RAND
      IF (NX-MSWP) 110, 120, 120
110   MINEX(J)=NULL-2
      MINEY(J)=MINEX(J)
120   CONTINUE
130   CONTINUE
```

The mine sweepers now enter the operation and attempt to sweep the channel clear of mines. In this partial program: NRMSWP is the number of mine sweepers in this play of the game, MSWEP(I) is the entry point into the channel for mine sweeper I, MSWWID is the

effective mine sweeper sweep width, NLOLIM is the lower X coordinate and NUPLIM is the upper X coordinate for the limits on the sweep width of mine sweeper I, and MSWP is the probability of the mine sweeper detecting and destroying a mine within its effective sweep width. The computation in this partial program enters each mine sweeper into the channel, one at a time, determines the limits of the mine sweeper's sweep width and passes the mine sweeper straight through the channel by comparing the values NLOLIM and NUPLIM with the values of MINEX(J) of the reordered minetable. When NLOLIM < MINEX(J)<NUPLIM mine number J is examined to determine if this mine sweeper detects and destroys the mine. The outcome of the event detect and destroy is determined by comparing a random number, NX, with MSWP. If NX <MSWP the mine is destroyed and this mine is nulled from the minetable by setting MINEX(J) and MINEY(J) equal to NULL-2. If NX ≥MSWP the mine is not destroyed. This computation is repeated for each mine sweeper. With the completion of this partial program the mine sweeping phase of the operation is completed.

```
140 NSAFE=0
    NSUNK=0
    NRNC=NCHW-NSXL*2
    DO 190 I=1, NRSH
    CALL RAND
    NT1=NXIN
    CALL RAND
    NLOLIM=(NXIN+NT1)/2+NSXL-NSW/2-1
    NUPLIM=NLOLIM+NSW+2
    DO 185 N=1, NRMINE
    IF (NLOLIM-MINEX(N)) 150, 185, 185
```

```
150 IF (MINEX(N)-NUPLIM) 160, 185, 185
160 CALL RAND
    IF (NX-NSP) 170, 180, 180
170 MINEX(N)=NULL-3
    MINEY(N)=MINEX(N)
    NSUNK=NSUNK+1
    GO TO 190
180 MINEX(N)=NULL-4
    MINEY(N)=MINEX(N)
185 CONTINUE
    NSAFE=NSAFE+1
190 CONTINUE
```

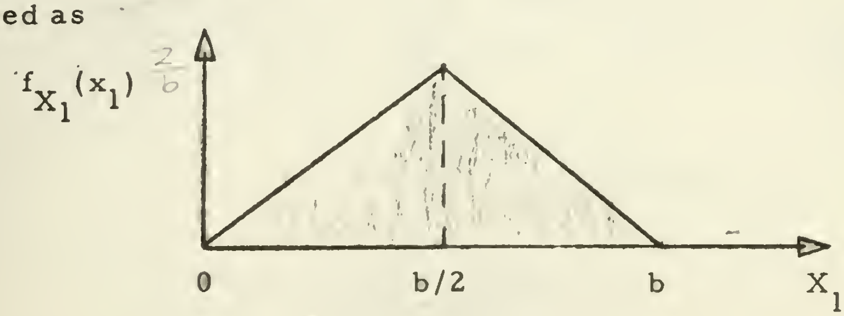
The next and last phase of the operation is for transits to pass through the channel and to determine how many of those attempting to transit are stopped from doing so because of any remaining mines. In this partial program NSAFE and NSUNK are the cumulative total number of successful and unsuccessful transits respectively, NCHW is the width of the channel, NSXL and NCHW-NSXL are the lower and upper limits, respectively, on the range of entry points into the channel for the transits, NSW is the effective width of the transits that will activate the mines, NLOLIM and NUPLIM are the computed lower and upper limits on the effective width of the transits as a function of transit entry point, and NSP is the probability that a mine in the effective width range of any transit will activate and destroy the transit. This computation enters each transit, one at a time, computes an entry point for the transit assuming the distribution of entry points is triangular, see Figure 3, and then computes the values of NLOLIM and NUPLIM. Once these values have been computed the transit passes through the channel in the same fashion as the mine sweepers. In this

operation, however, when a mine is encountered a random number is compared with NSP to determine if the mine has destroyed the transit. It is assumed that all mines so encountered are activated. For mines activated but not destroying the transit the mine is eliminated from the minetable by replacing its coordinates with NULL-4. For mines activated and destroying the transits the mine coordinates are nulled and replaced by NULL-3. The method for generating the entry points of the transits according to the characteristics of a triangular distribution is to take the average of two uniformly distributed random numbers, NXIN and NT1, in the interval (0, NCHW-(NSXL)*2) and add to this value the value of NSXL. This computation is detailed as follows for the interval (0, b):

let $$f_{X_1}(x_1) = \frac{4x_1}{b^2} \qquad 0 \le x_1 \le \frac{b}{2}$$

$$= -\frac{4x_1}{b^2} + \frac{4}{b} \qquad b/2 \le x_1 \le b$$

illustrated as

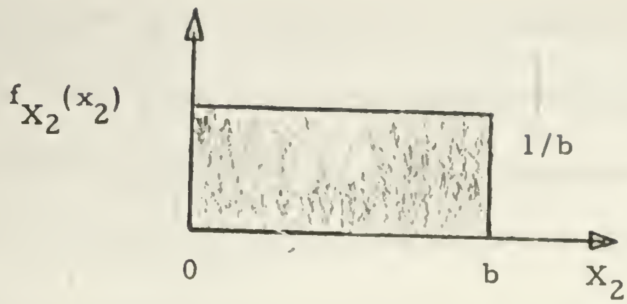


and

$$f_{X_2}(x_2) = 1/b \qquad 0 \le x_2 \le b$$

$$f_{X_3}(x_3) = 1/b \qquad 0 \le x_3 \le b$$

illustrated as



For: (1) $a \le b/2$

$$P(x_1 \le a) = \int_0^a 4x_1/b^2 \, dx_1 = 2a^2/b^2$$

$$P\left(\frac{x_2+x_3}{2} \le a\right) = \int_0^{2a} \int_0^{2a-x_3} 1/b^2 \, dx_2 \, dx_3 = 2a^2/b^2$$

and

for: (2) $b/2 \le a \le b$

$$P(x_1 \le a) = 1/2 + \int_{b/2}^{a} (-4x_1/b^2 + 4/b) \, dx_1 = 4a/b - 2a^2/b^2 - 1$$

$$P\left(\frac{x_2+x_3}{2} \le a\right) = \int_{2a-b}^{b} \int_0^{2a-x_3} 1/b^2 \, dx_2 \, dx_3$$

$$+ \int_0^{2a-b} \int_0^{b} 1/b^2 \, dx_2 \, dx_3$$

$$= 4a/b - 2a^2/b^2 - 1 .$$

and it is seen that

$$P(x_1 \le a) = P\left(\frac{x_2 + x_3}{2} \le a\right)$$

Up to this point nothing has been said about the units assigned to the (X, Y) coordinates of the playing area. Actually these units have no effect on the program - the model user may use any unit he desires as long as the units remain consistent for all program inputs.

The units, of course, are not entered into the program.

At this point in the program the simulation is complete. The remainder of the program is the computation necessary for a statistical tabulation of the results as found in the computer output, described in Section V, and the necessary instructions to replay the simulation to increase the sample size and to replay the simulation with different values assigned to the input parameters, described in Section IV. An interesting feature of the model is that the method of eliminating mines from the minetable is such that the minetable can be scanned to determine which mines were eliminated from the table and why, i. e., all mine locations in the minetable such that MINEX(J) is equal to NULL-3 indicates that mine number J of the reordered minetable was eliminated because this mine was activated and destroyed a transit, etc. Although it is not done in the program an analyst could add to the program, if he desired, the necessary instructions to scan the minetable at the end of the simulation and tabulate the number of mines and the reasons why they were eliminated during the play of the game.

To generate data for statistical purposes, the subroutine MINSIM is played a number of times--the exact number being specified as an input parameter.

To complete this section the complete MSF CDC-FORTRAN-60 program is included followed by a set of detailed flow charts of the program, Figure 5.

```
      PROGRAM MSF
      DIMENSION NRMPAC(50),NACEPT(50),MINED(300),MINENR(300),MINEX(300),
     1MINEY(300),MSWEP(50),NSAMSZ(100),FSAMSZ(100),SAMPLE(100)
C
      COMMON MSWP1,MSWP2,NSP1,NSP2,NRSAMP,NSAMSZ,FSAMSZ
      COMMON MSWP,NSP,NSAFE
      COMMON NRAIR,NRMPAC,NACEPT,MINED,NRMINE,MINENR,MINEX,MINEY,NRMSWP,
     1MSWEP,MSWWID,NRSH,NSW,NSXL,NCHW,NCHL,NXERR1,NYERR1,NXERRS,NYERRS,
     2NCHANW,NCHANL,FSPSE
      COMMON INDX,NX,NRNC,NXIN,NRC,NSTRN
      COMMON NDISC,INCM,INC,NRC2,NRC1
      COMMON ITRAN
   10 ITRAN =1
      NRC=0
      INDX=6
      READ INPUT TAPE 5, 1001,INAME1,INAME2
 1001 FORMAT(2A8)
      PRINT 9991, INAME1, INAME2
      WRITE OUTPUT TAPE 6, 9991, INAME1,INAME2
 9991 FORMAT (1H1,3X,2A8,///)
      CALL INPUT
      CALL TITLE
      CALL MS2
      GO TO 10
      END
      SUBROUTINE MS2
C
C     FORTRAN VERSION OF MINESWEEP PROB.                     RHS 7-12-62
C
      DIMENSION NRMPAC(50),NACEPT(50),MINED(300),MINENR(300),MINEX(300),
     1MINEY(300),MSWEP(50),NSAMSZ(100),FSAMSZ(100),SAMPLE(100)
C
      COMMON MSWP1,MSWP2,NSP1,NSP2,NRSAMP,NSAMSZ,FSAMSZ
      COMMON MSWP,NSP,NSAFE
      COMMON NRAIR,NRMPAC,NACEPT,MINED,NRMINE,MINENR,MINEX,MINEY,NRMSWP,
     1MSWEP,MSWWID,NRSH,NSW,NSXL,NCHW,NCHL,NXERR1,NYERR1,NXERRS,NYERRS,
     2NCHANW,NCHANL,FSPSE
      COMMON INDX,NX,NRNC,NXIN,NRC,NSTRN
      COMMON NDISC,INCM,INC,NRC2,NRC1
      COMMON ITRAN
C
C
      NCHANW=NCHW+1
      NCHANL=NCHL+1
      NRC=0
C
      INCM=0
      DO 40 I=1,NRSAMP
      MING=1000
      MAXG=0
      NOUT1=I
      NOUT2=NSAMSZ(I)
      FSPSM=0.
      NRC2=NSTRN+INCM
      INC=0
      DO 20 J=1,NOUT2
```

```
      CALL MINSIM
      INC=INC+NDISC
      FSPSE=NSAFE
      SAMPLE(J)=FSPSE
      MING=XMINOF(MING,NSAFE)
      MAXG=XMAXOF(MAXG,NSAFE)
   13 EMAXG=FSPSE
   20 FSPSM=FSPSM+FSPSE
      INCM=INCM+NDISC
      OUT3=FSPSM/FSAMSZ(I)
      SAMAVE=OUT3
      STORE=0.
      DO 30 K=1,NOUT2
      TEMP=SAMPLE(K)-SAMAVE
   30 STORE=STORE+TEMP**2
      OUT4=STORE/(FSAMSZ(I)-1.)
   40 WRITE OUTPUT TAPE 6,2001,NOUT1,NOUT2,OUT3,OUT4,MING,MAXG
 2001 FORMAT (10X,I3,11X,I3,10X,F5.2,9X,F7.4,12X,I3,15X,I3)
      RETURN
      END
      SUBROUTINE TITLE
      DIMENSION NRMPAC(50),NACEPT(50),MINED(300),MINENR(300),MINEX(300),
     1MINEY(300),MSWEP(50),NSAMSZ(100),FSAMSZ(100),SAMPLE(100)
C
      COMMON MSWP1,MSWP2,NSP1,NSP2,NRSAMP,NSAMSZ,FSAMSZ
      COMMON MSWP,NSP,NSAFE
      COMMON NRAIR,NRMPAC,NACEPT,MINED,NRMINE,MINENR,MINEX,MINEY,NRMSWP,
     1MSWEP,MSWWID,NRSH,NSW,NSXL,NCHW,NCHL,NXERR1,NYERR1,NXERRS,NYERRS,
     2NCHANW,NCHANL,FSPSE
      COMMON INDX,NX,NRNC,NXIN,NRC,NSTRN
      COMMON NDISC,INCM,INC,NRC2,NRC1
      COMMON ITRAN
C
      WRITE OUTPUT TAPE 6,2000,NRSH,NRMINE
 2000 FORMAT (1X ,34X,34HA PROBLEM IN MINE FIELD SIMULATION//20X,24HNUMB
     1ER OF SHIPS SCORED (I3,26H SHIPS THROUGH A FIELD OF I3, 7H MINES))
C
      WRITE OUTPUT TAPE 6,2001,NRMSWP,MSWWID,MSWP1,MSWP2
 2001 FORMAT (//// 5X,I2,20H MINE SWEEPER PASSES,29X,31HEFFECTIVE MINE S
     1WEEPER WIDTH = I3/5X,47HPROBABILITY OF MINE SWEEPER ELIMINATING MI
     2NE = I4,1H/,I4)
      IF (NRMSWP) 3,5,3
    3 WRITE OUTPUT TAPE 6,3001,(MSWEP(I),I=1,NRMSWP)
 3001 FORMAT (///39X,25HMINE SWEEPER ENTRY POINTS//(6X,10I9))
C
    5 WRITE OUTPUT TAPE 6,2002,       NXERR1,NXERRS,NYERR1,NYERRS
 2002 FORMAT (///14X,16HDELIVERY VEHICLE,14X,11HENTRY ERROR,16X,16HMINE
     1RANGE ERROR//16X,12HX-COORDINATE,19X,I4,25X,I4/16X,12HY-COORDINATE
     2,19X,I4,25X,I4)
C
      WRITE OUTPUT TAPE 6,2003
 2003 FORMAT (///4X,16HDELIVERY VEHICLE,6X,6HNUMBER,10X,5HENTRY,19X,17HM
     1INE DISTRIBUTION/9X,6HNUMBER,10X,8HOF MINES,9X,5HPOINT)
      J1=1
      DO 10 I=1,NRAIR
      J2=J1+NRMPAC(I)-1
```

```
      J3=XMINOF(J1+4,J2)
      WRITE OUTPUT TAPE 6,2004,I,NRMPAC(I),NACEPT(I),(MINED(J),J=J1,J3)
 2004 FORMAT (11X,I2,15X,I2,12X,I4,6X,5(3X,I5))
      IF (J2-J3) 10,10,9
    9 J3=J3+1
      WRITE OUTPUT TAPE 6,2007,(MINED(J),J=J3,J2)
 2007 FORMAT (52X,5I8)
   10 J1=J2+1
C
      WRITE OUTPUT TAPE 6,2005,NSW,NSXL,NSP1,NSP2,NCHW,NCHL
 2005 FORMAT (///5X,23HEFFECTIVE SHIP WIDTH = I3/5X,51HMINIMUM DISTANCE
     1BETWEEN CHANNEL AND SHIP CENTER = I3/5X,41HPROBABILITY OF A SHIP E
     2XPLODING A MINE = I4,1H/,I4/5X,16HCHANNEL WIDTH = I5,30X,17HCHANNE
     3L LENGTH = I5)
C
      WRITE OUTPUT TAPE 6,2006
 2006 FORMAT (///1X,3(8X,6HSAMPLE),9X,6HSAMPLE,10X,7HMINIMUM,11X,7HMAXIM
     1UM/9X,6HNUMBER,9X,4HSIZE,10X,4HMEAN,9X,8HVARIANCE,2(8X,10HSHIPS SA
     2FE)//)
C
      RETURN
      END
      SUBROUTINE MINSIM
C
      DIMENSION NRMPAC(50),NACEPT(50),MINED(300),MINENR(300),MINEX(300),
     1MINEY(300),MSWEP(50),NSAMSZ(100),FSAMSZ(100),SAMPLE(100)
C
      COMMON MSWP1,MSWP2,NSP1,NSP2,NRSAMP,NSAMSZ,FSAMSZ
      COMMON MSWP,NSP,NSAFE
      COMMON NRAIR,NRMPAC,NACEPT,MINED,NRMINE,MINENR,MINEX,MINEY,NRMSWP,
     1MSWEP,MSWWID,NRSH,NSW,NSXL,NCHW,NCHL,NXERR1,NYERR1,NXERRS,NYERRS,
     2NCHANW,NCHANL,FSPSE
      COMMON INDX,NX,NRNC,NXIN,NRC,NSTRN
      COMMON NDISC,INCM,INC,NRC2,NRC1
      COMMON ITRAN
      EQUIVALENCE (NULL,ULL)
B     ULL=3777 7777 7777 7777
      NRC=0
      ITRAN=1
      INDX=6
    5 IF (NRC2-NRC) 6,7,6
    6 CALL RAND
      GO TO 5
    7 CONTINUE
      DO 10 I=1,NRMINE
      MINENR(I)=0
      MINEX(I)=NULL
   10 MINEY(I)=NULL
      J=1
      DO 20 I=1,NRAIR
      NRNC=NYERR1
      CALL RAND
      MINEY(J)=NXIN+MINED(J)-NYERR1/2
      NRNC=NXERR1
      CALL RAND
      MINEX(J)=NXIN+NACEPT(I)-NXERR1/2
```

```
      MINENR(J)=J
   20 J=J+NRMPAC(I)
      DO 30 J=1,NRMINE
   21 IF (MINEY(J)-NULL) 30,22,30
   22 NRNC=NYERRS
      CALL RAND
      MINEY(J)=NXIN+MINED(J)+MINEY(J-1)-NYERRS/2
C
      NRNC=NXERRS
      CALL RAND
      MINEX(J)=NXIN+MINEX(J-1)-NXERRS/2
      MINENR(J)=J
   30 CONTINUE
C
C     LIMIT
C
      DO 40 I=1,NRMINE
      IF (MINEX(I)) 39,38,38
   38 IF (MINEY(I))39,37,37
   39 MINEX(I) = NULL-7
      MINEY (I) = MINEX(I)
   37 IF (MINEY(I)-NCHANL) 31,33,33
   31 IF (MINEX(I)-NCHANW) 40,33,33
   33 MINEY(I)=NULL-1
      MINEX(I) = MINEY(I)
   40 CONTINUE
C
C     SORT MINE TABLE
C
      J=NRMINE
   50 K=J
      J1=J-1
      DO 60 I=1,J1
      IF (MINEY(I)-MINEY(K)) 55,60,60
   55 K=I
   60 CONTINUE
      NT1=MINENR(J)
      MINENR(J)=MINENR(K)
      MINENR(K)=NT1
      NT1=MINEX(J)
      MINEX(J)=MINEX(K)
      MINEX(K)=NT1
      NT1=MINEY(J)
      MINEY(J)=MINEY(K)
      MINEY(K)=NT1
      J=J-1
      IF (J-1) 70,70,50
C
C     MINE SWEEPER PASS
C
   70 NRC1=NRC+INC
   81 IF(NRC1-NRC) 82,83,82
   82 CALL RAND
      GO TO 81
   83 IF(NRMSWP) 140,140,85
   85 DO 130 I=1,NRMSWP
```

```
      NLOLIM=MSWEP(I)-MSWWID/2 -1
      NUPLIM=NLOLIM+MSWWID +2
      DO 120 J=1,NRMINE
      IF (NLOLIM-MINEX(J)) 90,120,120
   90 IF (MINEX(J)-NUPLIM) 100,120,120
  100 CALL RAND
      IF (NX-MSWP) 110,120,120
  110 MINEX(J)=NULL-2
      MINEY(J)=MINEX(J)
  120 CONTINUE
  130 CONTINUE
C
C     SHIP START
C
  140 NSAFE=0
      NSUNK=0
      NRNC=NCHW-NSXL*2
      DO 190 I=1,NRSH
      CALL RAND
      NT1=NXIN
      CALL RAND
      NLOLIM=(NXIN+NT1)/2+NSXL-NSW/2-1
      NUPLIM=NLOLIM+NSW+2
      DO 185 N=1,NRMINE
      IF (NLOLIM-MINEX(N)) 150,185,185
  150 IF (MINEX(N)-NUPLIM) 160,185,185
  160 CALL RAND
      IF (NX-NSP) 170,180,180
  170 MINEX(N)=NULL-3
      MINEY(N)=MINEX(N)
      NSUNK=NSUNK+1
      GO TO 190
  180 MINEX(N)=NULL-4
      MINEY(N)=MINEX(N)
  185 CONTINUE
C
      NSAFE=NSAFE+1
  190 CONTINUE
  200 RETURN
      END
      SUBROUTINE INPUT
      DIMENSION NRMPAC(50),NACEPT(50),MINED(300),MINENR(300),MINEX(300),
     1MINEY(300),MSWEP(50),NSAMSZ(100),FSAMSZ(100),SAMPLE(100)
C
      COMMON MSWP1,MSWP2,NSP1,NSP2,NRSAMP,NSAMSZ,FSAMSZ
      COMMON MSWP,NSP,NSAFE
      COMMON NRAIR,NRMPAC,NACEPT,MINED,NRMINE,MINENR,MINEX,MINEY,NRMSWP,
     1MSWEP,MSWWID,NRSH,NSW,NSXL,NCHW,NCHL,NXERR1,NYERR1,NXERRS,NYERRS,
     2NCHANW,NCHANL,FSPSE
      COMMON INDX,NX,NRNC,NXIN,NRC,NSTRN
      COMMON NDISC,INCM,INC,NRC2,NRC1
      COMMON ITRAN
   10 READ INPUT TAPE 5,1000,NAME,N1,N2,NSEQ
 1000 FORMAT (A6,2I6,54X,A8)
C
      IF (NAME-5HNRAIR) 40,20,40
```

```
   20 NRAIR=N1
      READ INPUT TAPE 5,1001,(NRMPAC(I),NACEPT(I),I=1,NRAIR)
 1001 FORMAT (12I6)
      NRMINE =0
      DO 30 I=1,NRAIR
   30 NRMINE =NRMINE +NRMPAC(I)
      READ INPUT TAPE 5,1001,(MINED(I),I=1,NRMINE )
      GO TO 10
C
   40 IF (NAME-6HNRMSWP) 52,50,52
   50 NRMSWP=N1
      GO TO 10
C
   52 IF (NAME-5HMSWEP) 58,54,58
   54 READ INPUT TAPE 5,1001,(MSWEP (I),I=1,NRMSWP)
      GO TO 10
C
   58 IF (NAME-6HMSWWID) 70,60,70
   60 MSWWID=N1
      GO TO 10
C
   70 IF (NAME-6HSHIPWD ) 90,80,90
   80 NSW=N1
      NSXL=N2
      GO TO 10
C
   90 IF (NAME-4HXERR) 110,100,110
  100 NXERR1=N1
      NXERRS=N2
      GO TO 10
C
  110 IF (NAME-4HYERR) 130,120,130
  120 NYERR1=N1
      NYERRS=N2
      GO TO 10
C
  130 IF (NAME-6HNRSAMP) 160,140,160
  140 NRSAMP=N1
      READ INPUT TAPE 5,1001,(NSAMSZ(I),I=1,NRSAMP)
      DO 150 I=1,NRSAMP
  150 FSAMSZ(I)=NSAMSZ(I)
      GO TO 10
C
  160 IF (NAME-3HCHW) 180,170,180
  170 NCHW=N1
      NCHANW=NCHW+1
      GO TO 10
C
  180 IF (NAME-3HCHL) 200,190,200
      NCHANL=NCHL+1
  190 NCHL=N1
      GO TO 10
C
  200 IF (NAME-5HIRAND) 220,210,220
  210 ITRAN=1
      INDX=6
```

```
      GO TO 10
C
  220 IF (NAME-5HNRAND) 235,230,235
  230 NSTRN=N1
      GO TO 10
C
  235 IF (NAME-5HNDISC) 240,236,240
  236 NDISC=N1
      GO TO 10
C
  240 IF (NAME-4HNRSH) 260,250,260
  250 NRSH=N1
      GO TO 10
C
  260 IF (NAME-4HPMSW) 280,270,280
  270 MSWP1=N1
      MSWP2=N2
  275 LDA(MSWP1),ENQ(0),DVF(MSWP2),STA(MSWP).
      GO TO 10
C
  280 IF (NAME-3HPSH) 300,290,300
  290 NSP1=N1
      NSP2=N2
  295 LDA(NSP1),ENQ(0),DVF(NSP2),STA(NSP).
      GO TO 10
C
  300 IF (NAME-2HGO) 301,320,301
  301 IF (NAME-4HDUMP) 310,302,310
  302 CALL DUMP(0,32767,6)
      STOP
  310 WRITE OUTPUT TAPE 6,2001,NAME,N1,N2,NSEQ
 2001 FORMAT (1H1,31X,41HFOLLOWING DATA CARD CONTAINS ILLEGAL NAME//12X,
     1A6,2I6,54X,A8//46X,12HJOB DELETED.)
      STOP
C
  320 RETURN
      END
      SUBROUTINE RAND
C
C     RANDOM NUMBER GENERATOR
C
      DIMENSION XI(8),NXI(8)
      COMMON INDX,NX,NRNC,NXIN,NRC,NSTRN
      COMMON NDISC,INCM,INC,NRC2,NRC1
      COMMON ITRAN
      EQUIVALENCE (XI,NXI),(T1,NT1),(INDX,DX),(D1,ND1)
C
      GO TO (10,20),ITRAN
   10 ITRAN=2
B     XI(1)=3514 6016 2524 6131
B     XI(2)=0337 1363 2712 7740
B     XI(3)=1760 3011 0710 3016
B     XI(4)=0670 1154 5656 1316
B     XI(5)=1506 7663 7414 1566
B     XI(6)=2100 7160 3140 2631
B     XI(7)=1037 4327 7340 4007
```

```
C       XI(8)=0
C
   20   NRC=NRC+1
        L=INDX+1
        ND1=L
B       DX=D1*7
        M=INDX+1
         ND1=M
B       T1=D1*7
        N=NT1+1
        NXI(M)=NXI(L)+NXI(N)
B       XI(M)=XI(M)*3777 7777 7777 7777
        NX=NXI(M)
   30   LDA(NX),MUF(NRNC),STA(NXIN).
C
        RETURN
        END
        END
```

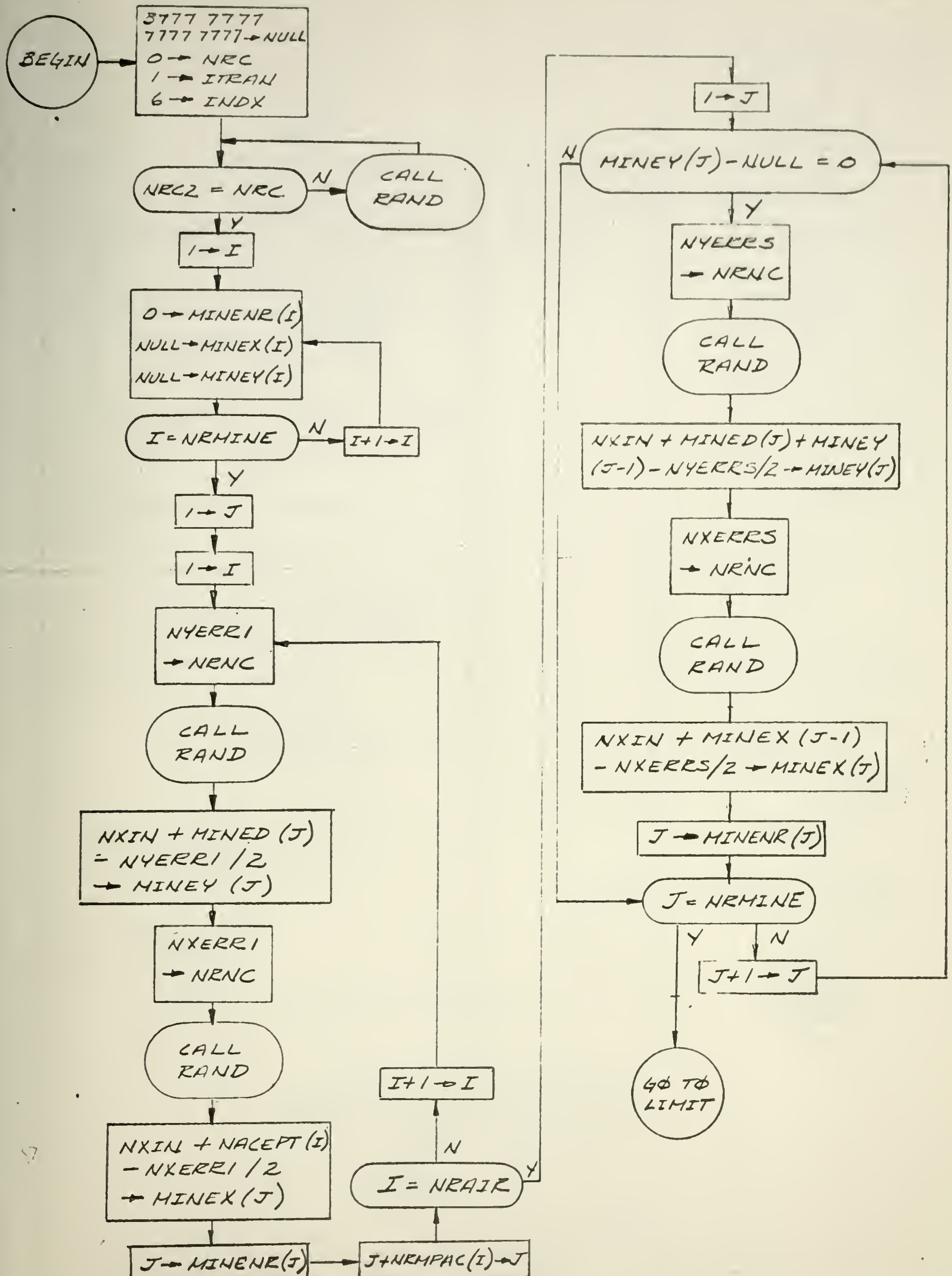

BEGIN
3777 7777
7777 7777 → NULL
0 → NRC
1 → ITRAN
6 → INDX
NRC2 = NRC
N
CALL RAND
Y
1 → I
0 → MINENR (I)
NULL → MINEX (I)
NULL → MINEY (I)
I = NRMINE
N
I+1 → I
Y
1 → J
1 → I
NYERR1 → NRNC
CALL RAND
NXIN + MINED (J) - NYERR1 /2 → MINEY (J)
NXERR1 → NRNC
CALL RAND
NXIN + NACEPT (I) - NXERR1 /2 → MINEX (J)
J → MINENR (J)
J+NRMPAC (I) → J
I = NRAIR
N
Y
I+1 → I
1 → J
MINEY (J) - NULL = 0
N
Y
NYERRS → NRNC
CALL RAND
NXIN + MINED (J) + MINEY (J-1) - NYERRS/2 → MINEY (J)
NXERRS → NRNC
CALL RAND
NXIN + MINEX (J-1) - NXERRS/2 → MINEX (J)
J → MINENR (J)
J = NRMINE
Y
N
J+1 → J
GØ TØ LIMIT

FIGURE 5

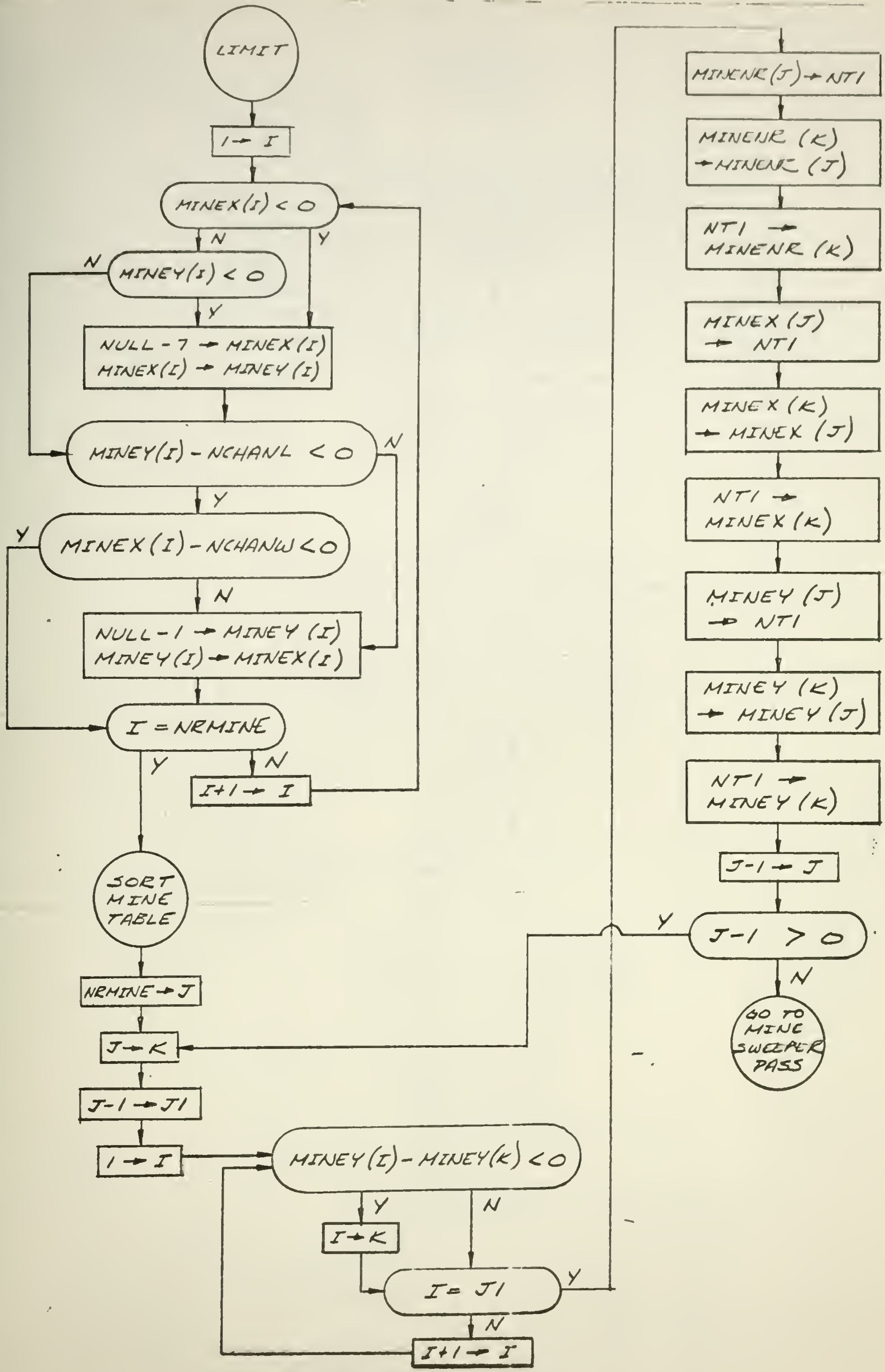


FIGURE 5 (Continued)

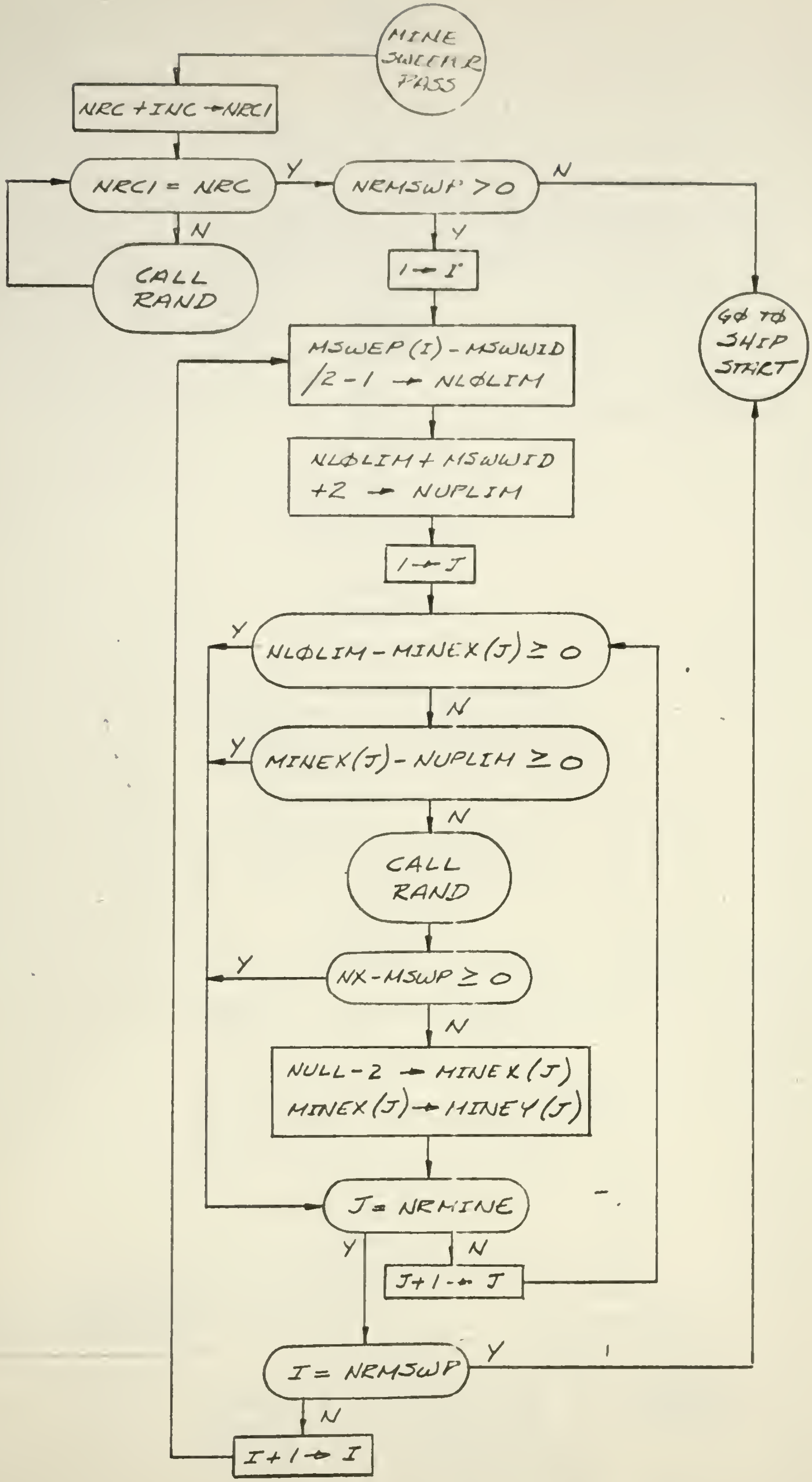


FIGURE 5 (Continued)

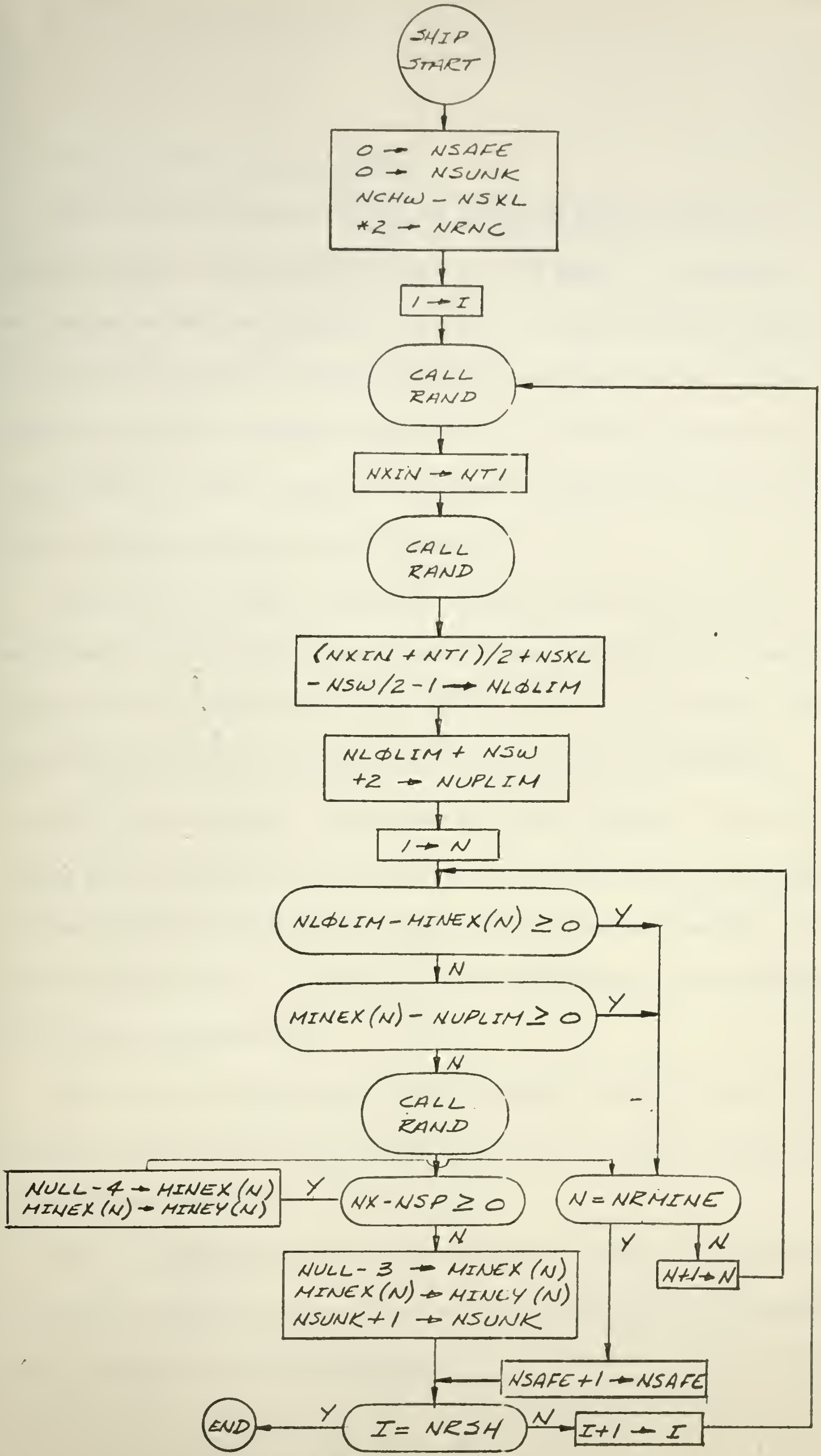


FIGURE 5 (Continued)

IV. Input Format and Description

Input data for MSF is entered on punch cards and read into the computer prior to the first replication of the game. A replication is a complete play of the game with one set of input data and consists of a specified number of samples, each with a specified size. The difference between samples is that a new mine field is generated for each sample, while a sample of size twenty indicates that twenty replays are made holding the mine field constant.

There are seventeen categories of input cards and except for the NAME card each input card is divided into a maximum of twelve fields with each field consisting of six consecutive card columns. The first field on a card is unique in that it may contain an alphabetic identifier which serves to distinguish data which follows. The identifying names are constant in the program and must never be changed by a user of the program unless the program itself is changed. It is only through program recognition of these names that subsequent input data will be properly read.

It is important that names entered in field 1 must be punched left-justified while all other data must be entered as integers right-justified in the proper card field.

The total number of input cards needed will depend upon the number of elements used in the game, that is, the number of delivery vehicles, mines, and mine sweepers required.

A description of all program inputs and related card formats follows. The order of punched cards in the input deck is as indicated by the order of description.

For the first replication of the game, a complete data card set must be punched. The entire sample set will be played, the statistics computed and the output printed by the MSF program.

For succeeding replications, it may be desirable to alter only the values of certain parameters, with the other values remaining the same as the previous input set. The use of the alphabetic identifiers allows a user to change only the desired parameters without duplicating the entire set of input cards; therefore, if a new replication is desired with only certain parameter values changed from the preceding replication it is only necessary to include all of the cards in the input card category containing the changed value of the parameter. When the MSF program has completed an execution with one set of input cards, the next set containing the changes will be read into memory leaving all other values the same as they were in the previous replication. For example if only the number of mine sweepers (NRMSWP) is to be changed for a second replication of the game, the following three cards would be sufficient for the next data card set:

```
NAME
NRMSWP   10
GO
```

This change indicates that the current replication is to be played using

the first ten mine sweepers of the last replication. If however the last replication contained less than ten mine sweepers it would also be necessary to include the cards in input card category number 3. The program inputs punched in input card category 3 would then have to contain inputs for all ten mine sweepers of the current replication.

Important to note is that the "NAME" and "GO" card must be respectively, the first and last card of each input deck. The GO card is a signal to the program that all parameter inputs have been completed and another replication of the game is to be played. If the starting value of the random number and the random number increment are not changed from replication to replication, the computed mine fields will remain constant for each replication, i. e., the mine field for sample 1, replication 1 will be the same as the mine field for sample 1, replication 2, etc.

CATEGORY	FIELD NR.	COLUMNS	DESCRIPTION
NAME	1	1-16	NAME OF MODEL USER
1	1	1-6	NRAIR identifies the following field and must be punched left justified.
	2	7-12	The total number of delivery vehicles, < 50.
1a	1	1-6	Total number of mines to be dropped by vehicle number 1.
	2	7-12	The desired entry point into the channel, X-coordinate, for vehicle number one.
	3	13-18	The same as fields 1 and 2 for vehicle number two.
	4	19-24	
	.	.	.
	.	.	.
	.	.	.
	11	61-66	Vehicle number six.
	12	67-72	
			Note: Use as many cards 1a as necessary to include all delivery vehicles. The second 1a card will contain information pertaining to vehicle number seven in fields 1 and 2, etc. The total number of mines in any play of the game must be <300.
1b	1	1-6	The desired Y-coordinate of the first mine dropped by vehicle number one.

CATEGORY	FIELD NR.	COLUMNS	DESCRIPTION
	2	7-12	The same as field 1 for the remaining mines dropped by vehicle number one, followed consecutively by the mines dropped by vehicle number two, etc. All Y coordinates, except the first, for each vehicle are additive.
	3	13-18	
	.	.	
	.	.	
	.	.	
	12	67-72	
			Note: Use as many cards 1b as necessary to include all mines for all vehicles.
2	1	1-6	NRMSWP identifies the following field and must be punched left justified.
	2	7-12	The total number of mine sweepers in this replication, < 50.
3	1	1-6	MSWEP identifies the following cards and must be punched left justified.
3a	1	1-6	The desired entry point into the channel, X-coordinate, for mine sweeper number one.
	2	7-12	The same as field 1 for mine sweeper number two, etc.
	.	.	
	.	.	
	.	.	
	12	67-72	
			Note: Use as many cards 3a as necessary to include all mine sweepers.
4	1	1-6	MSWWID identifies the following field and must be punched left justified.
	2	7-12	The effective sweep width of all mine sweepers.
5	1	1-6	SHIPWD identifies the following fields and must be punched left justified.

CATEGORY	FIELD NR.	COLUMNS	DESCRIPTION
	2	7-12	The effective width of all transiting ships.
	3	13-18	The minimum possible distance between the edge of the channel and the center of a transiting ship. This is the value NSXL of Figure 3.
6	1	1-6	XERR identifies the following fields and must be punched left justified.
	2	7-12	Maximum error in the X-direction for entry points of delivery vehicles.
	3	13-18	Maximum error in the X-direction for all subsequent mine locations.
7	1	1-6	YERR identifies the following fields and must be punched left justified.
	2	7-12	Maximum error in the Y-direction for entry points of delivery vehicles.
	3	13-18	Maximum error in the Y-direction for all subsequent mine locations.
8	1	1-6	NRSAMP identifies the following field and must be punched left justified.
	2	7-12	The number of samples of this replication.
8a	1	1-6	The size of sample number one.
	2	7-12	The same as field one for sample number two, etc.
	.	.	
	.	.	
	.	.	
	12	67-72	
			Note: Use as many cards 8a as necessary to include all samples.

CATEGORY	FIELD NR.	COLUMNS	DESCRIPTION
9	1	1-6	CHW identifies the following field and must be punched left justified.
	2	7-12	The channel width.
10	1	1-6	CHL identifies the following field and must be punched left justified.
	2	7-12	The channel length.
11	1	1-6	NRSH identifies the following field and must be punched left justified.
	2	7-12	The total number of transiting ships.
12	1	1-6	PMSW identifies the following fields and must be punched left justified.
	2	7-12	The probability that a mine sweeper detects and destroys a mine given that the mine is located within the effective sweep width of the mine sweeper. This probability is expressed as a fraction with the numerator in field 2 and the denominator in field 3.
	3	13-18	
13	1	1-6	PSH identifies the following fields and must be punched left justified.
	2	7-12	The probability that a mine actuates and destroys a transiting ship given that the mine is located within the effective width of the ship. This probability is expressed as a fraction with the numerator in field 2 and the denominator in field 3.
	3	13-18	
14	1	1-6	NRAND

CATEGORY	FIELD NR.	COLUMNS	DESCRIPTION
	2	7-12	The entry point in the random number table for the sequence of random numbers to be used in the play of the game.
15	1	1-6	NDISC
	2	7-12	The random number increment. This number is added to the number used on the last card to determine the entry point for succeeding sets of random numbers in order to generate a different set of numbers for each pass through the program. This value should be > 0.
GO	1	1-6	GO must be punched left justified. This card is a program required card to indicate the end of an input data deck.

As an illustration of a hypothetical problem and its associated inputs and how these inputs will appear on the input sheets the following example is included:

EXAMPLE:

Channel length = 10000
Channel width = 1000
Number of delivery vehicles = 5
Effective mine sweeper width = 150
Probability of mine sweeper detecting and destroying a mine = 5/16
Probability of mine activating and destroying a transit = 3/8
Number of transiting ships = 30
Effective width of transits = 40
Minimum distance between channel edge and transit ship center = 35
Maximum X-coordinate error for delivery vehicle entry = 200
Maximum Y-coordinate error for delivery vehicle entry = 300
Maximum X-coordinate error for mine location = 150
Maximum Y-coordinate error for mine location = 250

The desired minefield is as follows, and is illustrated in Figure 6.

delivery vehicle #	number of mines	desired entry	desired Y-coordinate for mine numbers							
			1	2	3	4	5	6	7	8
1	4	100	50	+200	+200	+200				
2	5	200	500	+200	+200	+200	+200			
3	3	300	1500	+500	+500					
4	4	500	1500	+400	+400	+800				
5	5	750	4000	+400	+400	+800	+500			

It is also desired that there be 10 samples each with a sample size of 100. There shall also be 6 replications. The first replication using 25 mine sweepers, the second 20, the third 15, the fourth 10, the fifth 5, and the sixth 0 mine sweepers. The entry points for the 25 mine

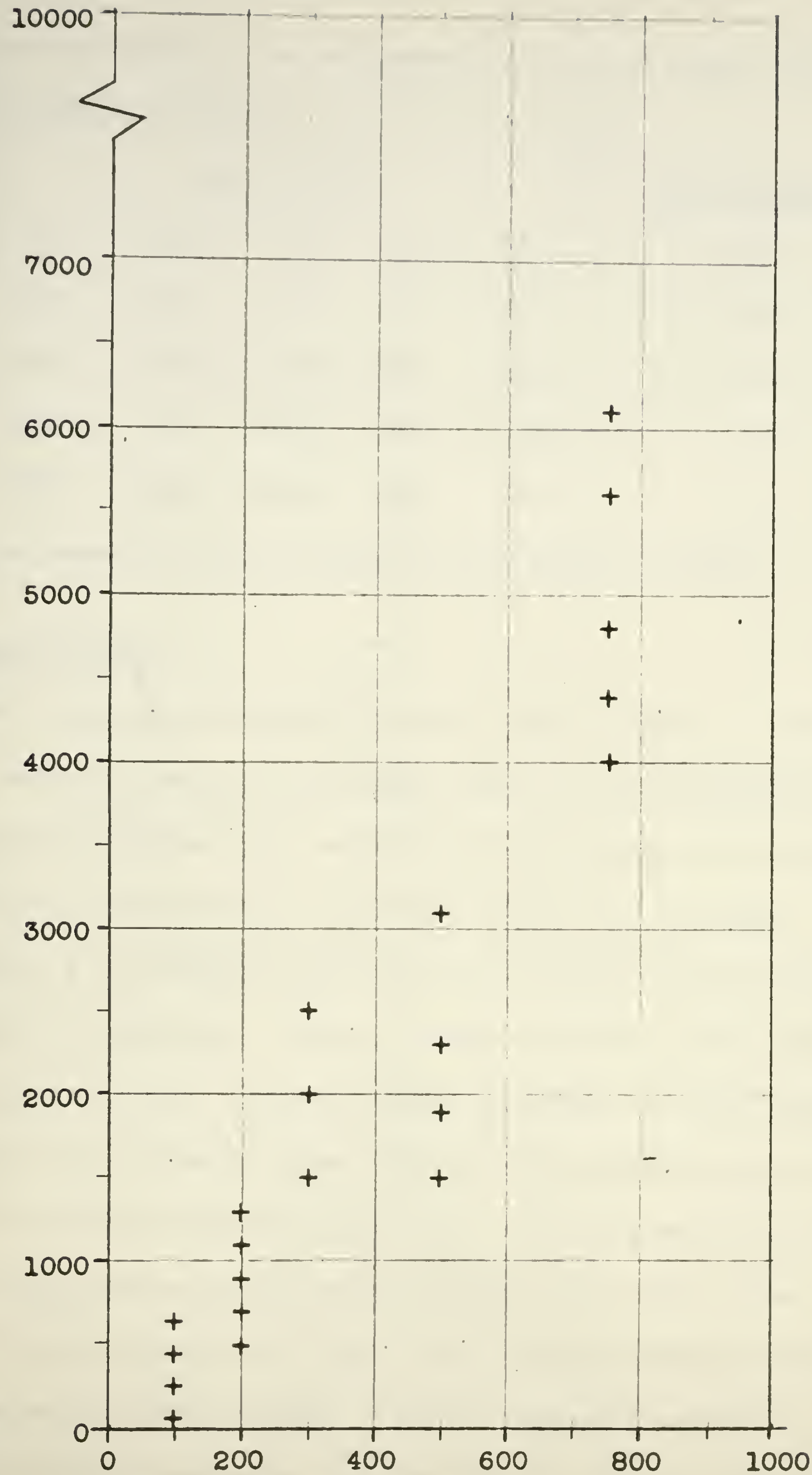

10000
7000
6000
5000
4000
3000
2000
1000
0
0
200
400
600
800
1000

FIGURE 6

sweepers of replication one are ordered from mine sweeper one to minesweeper 25 as follows:

Entry Points					Mine Sweeper #
500	400	600	300	700	1-5
200	800	100	900	200	6-10
800	300	700	400	600	11-15
500	500	400	600	300	16-20
700	400	600	500	500	21-25

The input sheet for this set of data is as illustrated in Figure 7.

V. Output Format

Each replication of the MSF program yields one page of output. The output consists of several of the input values for that replication plus a statistical tabulation of the sample mean and variance and the minimum and maximum number of the successful transit for each sample.

Figure 8 is a sample output page for one replication and contains the following information. Block I contains a title line and the number of transits and mines. Block II contains the number of mine sweepers, the mine sweeper effective sweep width, and the probability of a mine sweeper detecting and destroying a mine. Block III contains the mine sweeper entry points into the channel, ordered from left to right. Block IV contains maximum X and Y error values for delivery vehicle entry points and mine locations. Block V contains the number of delivery vehicles, the number of mines each is to drop, the desired

Coded By ______
Checked By ______

Identification 73 – 80

Date 9 FEB '66
Page 1 of 2

STATEMENT NUMBER (1–5)	Cont. (6)	FORTRAN STATEMENT (7–72)

```
ANDRUS-HØANG
NRAIR    5
    4  100    5  200    3  300    4  500    5  750
   50  200  200  200  500  200  200  200  200 1500  500  500
 1500  400  400  800 4000  400  400  800  500
NRMSWP  25
MSWEP
  500  400  600  300  700  200  800  100  900  200  800  300
  700  400  600  500  500  400  600  300  700  400  600  500
  500
MSWWID 150
SHIPWD  40   35
XERR   200  150
YERR   300  250
NRSAMP  10
  100  100  100  100  100  100  100  100  100  100
CHW   1000
CHL  10000
NRSH    30
PMSW     5   16
PSH      3    8
```

FIGURE 7

FORTRAN CODING FORM

Program MSF DATA (CONT'D)
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Checked By

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Date 9 FEB '66
Page 2 of 2

C FOR COMMENT.

```
NRAND       1
NDISC       1
GØ
ANDRUS-HØANG
NRMSWP     20
GØ
ANDRUS-HØANG
NRMSWP     15
GØ
ANDRUS-HØANG
NRMSWP     10
GØ
ANDRUS-HØANG
NRMSWP      5
GØ
ANDRUS-HØANG
NRMSWP      0
GØ
```

FIGURE 7 (CONT'D)

FIGURE 7 (Continued)

A PROBLEM IN MINE FIELD SIMULATION

NUMBER OF SHIPS SCORED (30 SHIPS THROUGH A FIELD OF 21 MINES) — I

---

25 MINE SWEEPER PASSES — EFFECTIVE MINE SWEEPER WIDTH = 150

PROBABILITY OF MINE SWEEPER ELIMINATING MINE = 5/ 16 — II

MINE SWEEPER ENTRY POINTS — III

500	400	600	300	700	200	800	100	900	200
800	300	700	400	600	500	500	400	600	300
700	400	600	500	500					

IV

DELIVERY VEHICLE	ENTRY ERROR	MINE RANGE ERROR
X-COORDINATE	200	150
Y-COORDINATE	300	250

V

DELIVERY VEHICLE NUMBER	NUMBER OF MINES	ENTRY POINT	MINE DISTRIBUTION				
1	4	100	50	200	200	200	
2	5	200	500	200	200	200	200
3	3	300	1500	500	500		
4	4	500	1500	400	400	800	
5	5	750	4000	400	400	800	500

EFFECTIVE SHIP WIDTH = 40

MINIMUM DISTANCE BETWEEN CHANNEL AND SHIP CENTER = 35

PROBABILITY OF A SHIP EXPLODING A MINE = 3/ 8

CHANNEL WIDTH = 1000 — CHANNEL LENGTH = 10000 — VI

VII

SAMPLE NUMBER	SAMPLE SIZE	SAMPLE MEAN	SAMPLE VARIANCE	MINIMUM SHIPS SAFE	MAXIMUM SHIPS SAFE
1	100	29.56	.3499	28	30
2	100	29.37	.4779	28	30
3	100	29.33	.5466	27	30
4	100	29.46	.4731	27	30
5	100	29.21	.6120	27	30
6	100	29.36	.3943	28	30
7	100	29.47	.4132	28	30
8	100	29.65	.2904	28	30
9	100	29.32	.7451	26	30
10	100	29.24	.7095	27	30

FIGURE 8

entry point into the channel for each vehicle, and the desired Y coordinate[1] for each mine the vehicle is to drop, ordered from left to right. Block VI contains the effective ship width, the channel length and width, the probability that a mine activates and destroys a transit, and the minimum distance between the channel edge and transit ship center in order to define the triangular distribution for transit ship entry points. Blocks I through VI have contained only the input values. Block VII contains the sample number, sample size, the mean and variance for the sample computed over the entire sample size for successful transits and the minimum and maximum values for successful transits computed over the entire sample size.

---

[1]As indicated by the input sheets all Y coordinates, except the first, for all vehicles are additive.

VI. Conclusions and Sample Output

For the sample problem given in the example of Section IV this section presents the six pages of computer output - one page per replication. No attempt has been made here to analyze the data or to draw conclusions from the data presented. This completes this phase of the problem presented in this report. A model has been constructed under simplifying assumptions, and the student should now be familiar enough with the model so that he can use it and understand the model output in light of the assumptions presented. It is also thought that the student familiar with FORTRAN programming will be able to change the program as desired.

Two points remain to be stressed however: (1) All that has been presented here is a model by which data are generated. If the data are acceptable to an analyst the problem of analyzing the data has yet to be done. This is true of all models similar to MSF. (2) MSF has been presented as a pedagogical tool for beginning students in Operations Analysis in an effort to familiarize them not only with MSF but also as an introduction to digital computer war gaming in general.

A PROBLEM IN MINE FIELD SIMULATION

NUMBER OF SHIPS SCORED (30 SHIPS THROUGH A FIELD OF 21 MINES)

25 MINE SWEEPER PASSES EFFECTIVE MINE SWEEPER WIDTH = 150
PROBABILITY OF MINE SWEEPER ELIMINATING MINE = 5/ 16

MINE SWEEPER ENTRY POINTS

500	400	600	300	700	200	800	100	900	200
800	300	700	400	600	500	500	400	600	300
700	400	600	500	500					

DELIVERY VEHICLE	ENTRY ERROR	MINE RANGE ERROR
X-COORDINATE	200	150
Y-COORDINATE	300	250

DELIVERY VEHICLE NUMBER	NUMBER OF MINES	ENTRY POINT	MINE DISTRIBUTION				
1	4	100	50	200	200	200	
2	5	200	500	200	200	200	200
3	3	300	1500	500	500		
4	4	500	1500	400	[illegible]	300	
5	5	750	4000	400	400	800	500

EFFECTIVE SHIP WIDTH = 40
MINIMUM DISTANCE BETWEEN CHANNEL AND SHIP CENTER = 35
PROBABILITY OF A SHIP EXPLODING A MINE = 3/ 8
CHANNEL WIDTH = 1000 CHANNEL LENGTH = 10000

SAMPLE NUMBER	SAMPLE SIZE	SAMPLE MEAN	SAMPLE VARIANCE	MINIMUM SHIPS SAFE	MAXIMUM SHIPS SAFE
1	100	29.56	.3499	28	30
2	100	29.37	.4779	28	30
3	100	29.33	.5466	27	30
4	100	29.46	.4731	27	30
5	100	29.21	.6120	27	30
6	100	29.36	.3943	28	30
7	100	29.47	.4132	28	30
8	100	29.65	.2904	28	30
9	100	29.32	.7451	26	30
10	100	29.24	.7095	27	30

A PROBLEM IN MINE FIELD SIMULATION

NUMBER OF SHIPS SCORED (30 SHIPS THROUGH A FIELD OF 21 MINES)

20 MINE SWEEPER PASSES
EFFECTIVE MINE SWEEPER WIDTH = 150
PROBABILITY OF MINE SWEEPER ELIMINATING MINE = 5/ 16

MINE SWEEPER ENTRY POINTS

500	400	600	300	700	200	800	100	900	200
800	300	700	400	600	500	500	400	600	300

DELIVERY VEHICLE	ENTRY ERROR	MINE RANGE ERROR
X-COORDINATE	200	150
Y-COORDINATE	300	250

DELIVERY VEHICLE NUMBER	NUMBER OF MINES	ENTRY POINT	MINE DISTRIBUTION				
1	4	100	50	200	200	200	
2	5	200	500	200	200	200	200
3	3	300	1500	500	500		
4	4	500	1500	400	400	800	
5	5	750	4000	400	400	800	500

EFFECTIVE SHIP WIDTH = 40
MINIMUM DISTANCE BETWEEN CHANNEL AND SHIP CENTER = 35
PROBABILITY OF A SHIP EXPLODING A MINE = 3/ 8
CHANNEL WIDTH = 1000, CHANNEL LENGTH = 10000

SAMPLE NUMBER	SAMPLE SIZE	SAMPLE MEAN	SAMPLE VARIANCE	MINIMUM SHIPS SAFE	MAXIMUM SHIPS SAFE
1	100	29.30	.5758	27	30
2	100	29.21	.6524	27	30
3	100	29.01	.7575	27	30
4	100	29.31	.5393	28	30
5	100	28.70	1.0000	27	30
6	100	29.25	.4924	27	30
7	100	29.25	.4520	27	30
8	100	29.36	.4752	28	30
9	100	29.09	.7494	27	30
10	100	29.02	.7269	27	30

A PROBLEM IN MINE FIELD SIMULATION

NUMBER OF SHIPS SCORED (30 SHIPS THROUGH A FIELD OF 21 MINES)

15 MINE SWEEPER PASSES — EFFECTIVE MINE SWEEPER WIDTH = 150
PROBABILITY OF MINE SWEEPER ELIMINATING MINE = 5/ 16

MINE SWEEPER ENTRY POINTS

500	400	600	300	700	200	800	100	900	200
800	300	700	400	600					

DELIVERY VEHICLE	ENTRY ERROR	MINE RANGE ERROR
X-COORDINATE	200	150
Y-COORDINATE	300	250

DELIVERY VEHICLE NUMBER	NUMBER OF MINES	ENTRY POINT	MINE DISTRIBUTION				
1	4	100	50	200	200	200	
2	5	200	500	200	200	200	200
3	3	300	1500	500	500		
4	4	500	1500	400	400	300	
5	5	750	4000	400	400	800	500

EFFECTIVE SHIP WIDTH = 40
MINIMUM DISTANCE BETWEEN CHANNEL AND SHIP CENTER = 35
PROBABILITY OF A SHIP EXPLODING A MINE = 3/ 8
CHANNEL WIDTH = 1000 — CHANNEL LENGTH = 10000

SAMPLE NUMBER	SAMPLE SIZE	SAMPLE MEAN	SAMPLE VARIANCE	MINIMUM SHIPS SAFE	MAXIMUM SHIPS SAFE
1	100	28.96	.9681	26	30
2	100	28.59	1.5777	25	30
3	100	28.45	.7753	26	30
4	100	29.10	.6162	27	30
5	100	28.33	1.2536	26	30
6	100	28.88	.7733	26	30
7	100	28.49	.9393	26	30
8	100	28.69	.8019	27	30
9	100	28.55	1.0177	25	30
10	100	28.91	.8504	26	30

A PROBLEM IN MINE FIELD SIMULATION

NUMBER OF SHIPS SCORED (30 SHIPS THROUGH A FIELD OF 21 MINES)

10 MINE SWEEPER PASSES
EFFECTIVE MINE SWEEPER WIDTH = 150
PROBABILITY OF MINE SWEEPER ELIMINATING MINE = 5/ 16

MINE SWEEPER ENTRY POINTS

500	400	600	300	700	200	800	100	900	200

DELIVERY VEHICLE	ENTRY ERROR	MINE RANGE ERROR
X-COORDINATE	200	150
Y-COORDINATE	300	250

DELIVERY VEHICLE NUMBER	NUMBER OF MINES	ENTRY POINT	MINE DISTRIBUTION				
1	4	100	50	200	200	200	
2	5	200	500	200	200	200	200
3	3	300	1500	500	500		
4	4	500	1500	400	400	800	
5	5	750	4000	400	400	800	500

EFFECTIVE SHIP WIDTH = 40
MINIMUM DISTANCE BETWEEN CHANNEL AND SHIP CENTER = 35
PROBABILITY OF A SHIP EXPLODING A MINE = 3/ 8
CHANNEL WIDTH = 1000
CHANNEL LENGTH = 10000

SAMPLE NUMBER	SAMPLE SIZE	SAMPLE MEAN	SAMPLE VARIANCE	MINIMUM SHIPS SAFE	MAXIMUM SHIPS SAFE
1	100	28.71	1.1979	26	30
2	100	28.25	1.2601	26	30
3	100	28.30	.8586	26	30
4	100	28.77	.9668	25	30
5	100	27.98	1.3733	25	30
6	100	27.79	1.6019	25	30
7	100	28.09	1.6181	25	30
8	100	28.70	.8384	26	30
9	100	28.39	1.1090	26	30
10	100	28.20	1.2525	25	30

A PROBLEM IN MINE FIELD SIMULATION

NUMBER OF SHIPS SCORED (30 SHIPS THROUGH A FIELD OF 21 MINES)

5 MINE SWEEPER PASSES   EFFECTIVE MINE SWEEPER WIDTH = 150
PROBABILITY OF MINE SWEEPER ELIMINATING MINE = 5/ 16

MINE SWEEPER ENTRY POINTS

500	400	600	300	700

DELIVERY VEHICLE	ENTRY ERROR	MINE RANGE ERROR
X-COORDINATE	200	150
Y-COORDINATE	300	250

DELIVERY VEHICLE NUMBER	NUMBER OF MINES	ENTRY POINT	MINE DISTRIBUTION				
1	4	100	50	200	200	200	
2	5	200	500	200	200	200	200
3	3	300	1500	500	500		
4	4	500	1500	400	400	800	
5	5	750	4000	400	400	800	500

EFFECTIVE SHIP WIDTH = 40
MINIMUM DISTANCE BETWEEN CHANNEL AND SHIP CENTER = 35
PROBABILITY OF A SHIP EXPLODING A MINE = 3/ 8
CHANNEL WIDTH = 1000   CHANNEL LENGTH = 10000

SAMPLE NUMBER	SAMPLE SIZE	SAMPLE MEAN	SAMPLE VARIANCE	MINIMUM SHIPS SAFE	MAXIMUM SHIPS SAFE
1	100	28.31	1.3878	25	30
2	100	27.62	1.6723	25	30
3	100	27.58	2.2663	23	30
4	100	27.86	1.8388	25	30
5	100	27.65	1.6843	24	30
6	100	27.16	2.8226	23	30
7	100	28.05	1.2803	25	30
8	100	28.55	1.1591	26	30
9	100	28.24	1.3762	24	30
10	100	27.92	1.8925	25	30

A PROBLEM IN MINE FIELD SIMULATION

NUMBER OF SHIPS SCORED (30 SHIPS THROUGH A FIELD OF 21 MINES)

0 MINE SWEEPER PASSES — EFFECTIVE MINE SWEEPER WIDTH = 150
PROBABILITY OF MINE SWEEPER ELIMINATING MINE = 5/ 16

DELIVERY VEHICLE	ENTRY ERROR	MINE RANGE ERROR
X-COORDINATE	200	150
Y-COORDINATE	300	250

DELIVERY VEHICLE NUMBER	NUMBER OF MINES	ENTRY POINT	MINE DISTRIBUTION				
1	4	100	50	200	200	200	
2	5	200	500	200	200	200	200
3	3	300	1500	500	500		
4	4	500	1500	400	400	800	
5	5	750	4000	400	400	800	500

EFFECTIVE SHIP WIDTH = 40
MINIMUM DISTANCE BETWEEN CHANNEL AND SHIP CENTER = 35
PROBABILITY OF A SHIP EXPLODING A MINE = 3/ 8
CHANNEL WIDTH = 1000 — CHANNEL LENGTH = 10000

SAMPLE NUMBER	SAMPLE SIZE	SAMPLE MEAN	SAMPLE VARIANCE	MINIMUM SHIPS SAFE	MAXIMUM SHIPS SAFE
1	100	28.01	1.6060	25	30
2	100	25.98	1.2117	24	29
3	100	26.88	2.1269	23	29
4	100	26.48	1.8481	23	30
5	100	26.05	1.8460	23	28
6	100	25.28	4.2844	21	28
7	100	27.04	2.1196	24	30
8	100	27.55	1.6237	25	30
9	100	27.04	2.2408	23	29
10	100	27.17	2.2031	23	30

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13. ABSTRACT

A probabilistic computer simulation, constructed under very simplifying assumptions, of mine sweeper operations is presented. The model is described along with its associated input and output formats. A listing of the CDC FORTRAN-60 program and a sample output from several computer runs are included. The model was constructed as a pedagogical tool in an attempt to familiarize beginning students of Operations Research with the Monte Carlo method as applied in computer war gaming.

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Monte Carlo						
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